Stock Assessment of Arctic Grayling and Rainbow Trout in Piledriver Slough During 1992

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March 1993

FISHERY DATA SERIES NO. 93-8

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PILEDRIVER SLOUGH DURING 1992[1]

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March 1993

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ABSTRACT

A detailed assessment of the Arctic grayling *Thymallus arcticus* population was conducted at Piledriver Slough, near Fairbanks, Alaska during 1992. A mark-recapture experiment was conducted, from which abundance, age and size composition of the Arctic grayling population were estimated. The timing of the investigation corresponded with spring break-up and the onset of a popular spring fishery, similar to past investigations. Fish were captured using pulsed direct current backpack electrofishing gear. An estimated 14,030 (SE = 1,860) Arctic grayling greater than 149 millimeter fork length were present during the May spawning period. The stock was characterized by a high proportion of sub-legal sized Arctic grayling (less than 260 millimeter fork length) and ages 4 and 5 predominated. Preliminary estimates of survival and exploitation indicated the stock of Arctic grayling may have a low survival rate and higher than expected exploitation rates. The results of a concurrent mark-recapture experiment on stocked rainbow trout *Oncorhynchus mykiss* indicated an overwinter survival of 0.25 percent for the 1991 stocking cohort.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, rainbow trout, *Oncorhynchus mykiss*, Piledriver Slough, abundance estimation, age composition, size composition, spawning stock, survival rate.

INTRODUCTION

Following Piledriver Slough's establishment as a clearwater stream in 1976 from the blocking of direct flow of the Tanana River, it has been colonized by many freshwater species common to interior Alaska (Timmons and Clark 1991). It is likely that Piledriver Slough was colonized by Arctic grayling *Thymallus arcticus* straying from area streams and rivers. Based on tagging information, likely donor stocks were from the adjoining Moose and French Creek watersheds as well as the more distant Chena and Salcha rivers. In the 15 years following the blocking of direct flow from the Tanana River, Arctic grayling have become well established in the slough with higher densities than other assessed populations in the Tanana River drainage. Hydrologically, the slough has attributes of both spring-fed and rapid run-off streams. Water enters the slough by upwelling from the Tanana aquifer; the height or stream-stage is influenced directly by glacial meltwater runoff in the Tanana River. Life history accounts within the Tanana River drainage have indicated that Arctic grayling utilize spring-fed systems for feeding but not spawning (Clark and Ridder 1988, Ridder 1989). Unlike other Tanana drainage spring creeks, Piledriver Slough provides habitat for both spawning and feeding. The close proximity of Piledriver Slough to Fairbanks (Figure 1), its accessibility, and abundances of both Arctic grayling and stocked rainbow trout, have led to the creation of a popular sport fishery. The increased use of Piledriver Slough by anglers seeking Arctic grayling and stocked rainbow trout in recent years has led to continued stock assessments and monitoring of these populations. Estimates from statewide harvest reports (Mills 1983-1992) indicate angler effort in the Piledriver Slough fishery has increased substantially since inception of the rainbow trout stocking program. Piledriver Slough has received an estimated 15% of the Tanana drainage effort in 1990 (days fished), provided as much as 20% of the drainage total catches of Arctic grayling in 1990 (Mills 1991), and yielded as much as 16% of the drainage harvest of rainbow trout in 1988 (Mills 1989).

In 1990, Arctic grayling stock assessment began at Piledriver Slough. Abundance and composition estimates provided initial information to monitor the population of Arctic grayling with respect to increased participation in the sport fishery (Timmons and Clark 1991). This study found a dense population of Arctic grayling and indications of low overwinter survival by stocked rainbow trout.

In 1991, abundance, stock composition, growth, maturity, and mixing rate parameters were estimated for Arctic grayling (Fleming 1991), and survival of stocked rainbow trout was estimated (Timmons 1992). Abundance of Arctic grayling was estimated at 17,323 fish (SE = 869) > 149 mm fork length (FL). The population was comprised primarily of ages 5 and 4 years, respectively, and stock size fish (< 270 mm FL). Age-length data was fitted to a von Bertalanffy growth model which indicated lower growth potential than most Tanana River drainage stocks under past or present study. Initial investigations into the timing of maturity suggested that approximately 50% maturity corresponds to 6 years of age, or a size between 250-259 mm FL. Refinements to this work by Clark (1992) included modeling the maturity function using Probit analysis (Finney 1971) which lowered the estimated age
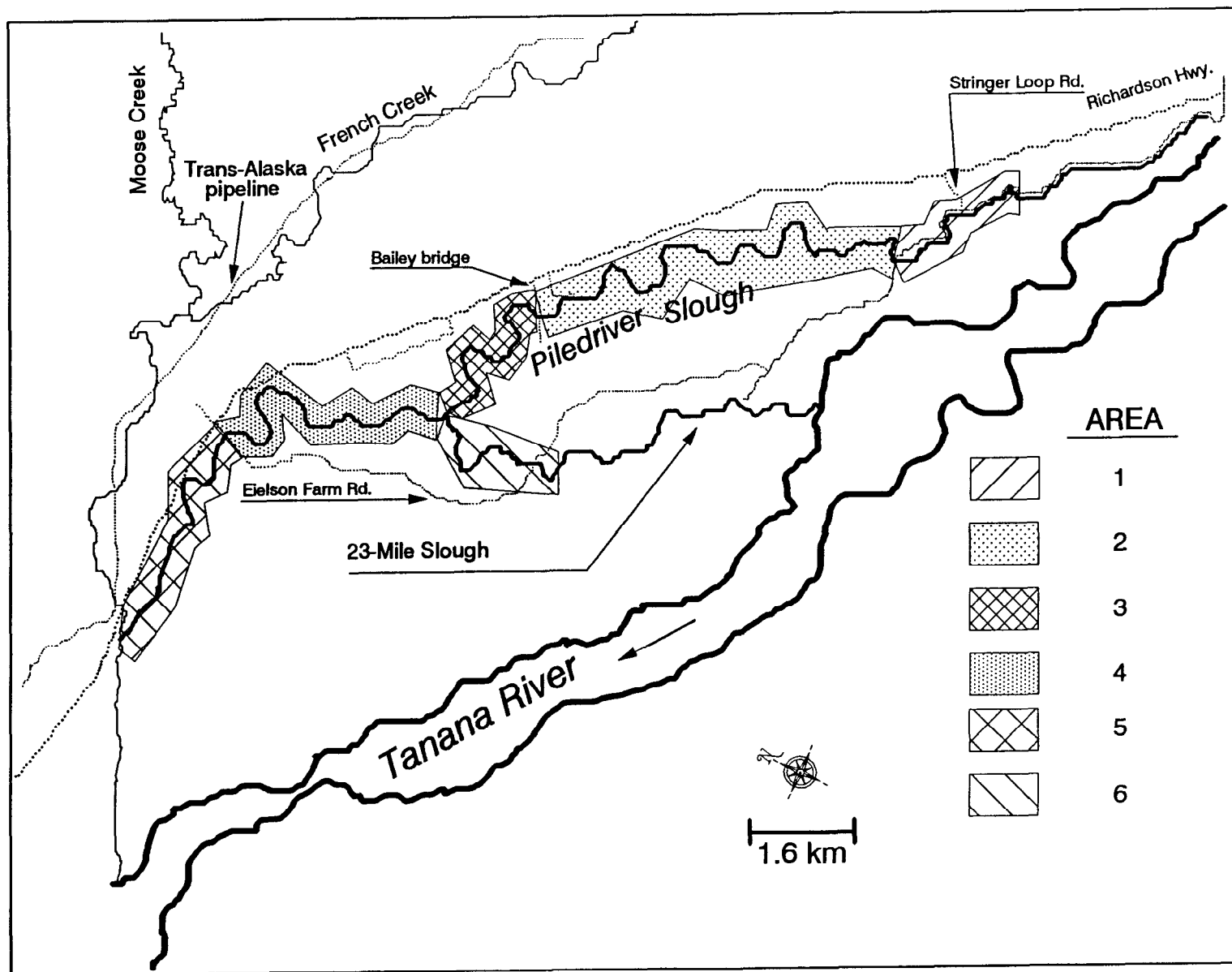
Figure 1. Map of study area encompassing Piledriver Slough, Moose Creek and French Creek.

corresponding to 50% maturity to between 4 and 5 years. Estimates of mixing rates indicated that nearly all (97%, SE = 17%) of the stock examined during the late-summer feeding period (August) had been present during the May sampling period. Additionally it was estimated that up to 50% of the stock examined in adjoining Moose Creek during July and August, had moved from Piledriver Slough sometime after tagging in May.

Survival of stocked rainbow trout from the time of stocking in 1990 to assessment in May 1991 was estimated by Timmons (1992) to be approximately 2%.

High levels of angling effort at Piledriver Slough require continued close monitoring to assure the fishery's sustainability. A current management objective is to ensure that harvest and incidental mortality of Arctic grayling is sustainable. In 1992, the objectives of the Piledriver Slough Arctic grayling and stocked rainbow trout assessment programs were to estimate:

1) abundance of Arctic grayling greater than 149 mm fork length (FL) in Piledriver Slough;

2) age composition of the Arctic grayling population in Piledriver Slough;

3) size composition of the Arctic grayling population in Piledriver Slough; and,

4) survival of the 1991 stocking cohort of rainbow trout from the time of stocking to May 1992.

Because this year's investigation allowed examination of the stock across two successive years, survival and mortality of Arctic grayling were estimated. The estimation of stocked rainbow trout survival is reported in Appendix B1.

METHODS

Field Sampling

The mark-recapture experiment in Piledriver Slough in 1992 was of shorter duration than that conducted in both 1990 and 1991. It began on 13 May 1992 in Piledriver Slough, following breakup, and was completed on 18 May along the main stem of Piledriver Slough. Two systematic sampling events were undertaken, using two electrofishing crews of five to seven people which allowed for efficient and timely coverage of the study area thereby minimizing risks of immigration into or emigration from the surveyed area and assessed stock. The marking event lasted three days; the recapture event lasted two days. In 1991, Piledriver Slough was divided into six areas delineated by landmarks, access points, or one crew-day's coverage (Figure 1). For the purpose of between-year consistency, this year's study used 1991 geographic delineations when possible. The areas of Piledriver Slough are described as follows:

Area 1)   Stringer Loop Road area: includes the section between the large beaver dam downstream to the culverts. This area is the headwaters of the slough; it is narrow, with alternating pools and riffles (one crew day).

Area 2)   Culverts to Bailey Bridge: this section of Piledriver Slough is a remote section, accessed from the ends. The stream is generally small with alternating pools, riffles, and minor braiding. The lower portion of this section also includes long runs and larger pools (two crew days).

Area 3)   Bailey Bridge to 23-Mile Slough: this section is easily accessed by a road and a path, respectively. In this section, a habitat transition occurs; the variability seen in the upstream areas is reduced. This section is generally wide and slow moving, with an increased volume. (one crew day)

Area 4)   23-Mile Slough to Eielson Farm Road: this section is easily accessed by a path and a road, respectively. This section is primarily broad and slow, with some deep pools (one and a half crew days).

Area 5)   Eielson Farm Road to confluence with the Tanana River: this portion of the slough was accessed and sampled using a pulse-DC electrofishing boat. The area is evenly divided between broad and slow and narrow channelized habitats (one boat crew day).

Area 6)   23-Mile Slough: this tributary slough is accessed 2 km upstream of the Eielson Farm Road by a path, and exited by a path near the confluence with Piledriver Slough. The habitat in the tributary is similar to area (1), but smaller in scale (one crew day).

Owing to the exceptionally late spring break-up, aufeis accumulations, and beaver dams which caused barriers to upstream migration, several headwater segments of Piledriver Slough assessed in 1991 could not be included in the 1992 mark-recapture experiment. Area (1) was closed to immigration of fish by several unbreached beaver dams. Following the melting of a heavy aufeis accumulation, crews found the partial remains of unidentified dead fish and no live fish present in the area. Access to the upper half of area (2), now referred to as area (2a), was blocked by beaver dams, and was found to be devoid of fish. In area (6) heavy accumulations of aufeis prevented access and use by spawning Arctic grayling as seen in 1991.

The upstream limit of the 1992 study section was at the beaver dam blockage delimiting areas (2a) and (2b). Areas within the 1992 study section included areas (2b), (3), and area (4), which was subdivided to areas (4a) and (4b). Efficient electrofishing capture techniques utilized in 1990 and 1991 sampling were used again; two backpack shockers were fished in tandem within each crew (Fleming 1991). In narrow reaches of the slough, a single electrofishing team

(one electrofisher and one dip netter) blocked pool tail-outs as the other team worked downstream towards them. In wider areas, both teams worked either side-by-side, or in a staggered formation, fishing downstream. Variable voltage pulsator (VVP) settings were 60 Hz pulse DC ranging from 200 to 250 volts and amperage from 1.5 to 2.0 A. All initially captured fish greater than 149 mm FL were measured to the nearest 1 mm FL, fin punched (upper caudal punch), and tagged with an individually numbered green Floy FD-67 internal anchor tag at the base of the dorsal fin. Sexual maturity was determined for each Arctic grayling by the release of eggs or milt. Several scales were collected from the area approximately six scale rows above the lateral line, just posterior to the dorsal fin's insertion of each Arctic grayling's left flank, and were later cleaned and mounted for ageing. Fork length, finclip and or fin punch tag number, and sex were recorded on Tagging-Length forms (Version 1.0). Fish with tag losses were given new tags, and previous finclips were noted. Scales from previously marked Arctic grayling were collected on the right side of the fish to avoid collection of regenerated scales. Data collection procedures from previously marked Arctic grayling were similar, but previous finclips, tag losses, tag numbers, and colors were recorded.

Abundance Estimation

The use of a closed model mark-recapture experiment to accurately estimate the abundance of Arctic grayling in Piledriver Slough in 1992 required differences to the approach used in 1991. The use of a closed model abundance estimator using mark-recapture experiments assumes the following (Seber 1982):

1) the population in the study area must be closed, i.e. the effects of migration, mortality, and recruitment are negligible;

2) all Arctic grayling have the same probability of capture during the first sample or in the second sample or marked and unmarked Arctic grayling mix randomly between the first and second samples;

3) marking of Arctic grayling does not affect their probability of capture in the second sample, and;

4) Arctic grayling do not lose their mark between sampling events.

The sampling design attempted to lessen risks associated with closure (assumption 1) by shortening the duration of the mark-recapture experiment considerably. It was highly improbable that substantial migration, mortality, or recruitment occurred during the three day hiatus. Sampling the majority of Piledriver Slough in both events was desired to reduce any effects of recruitment during the experiment and improve accuracy of the assessment. Assumptions 2 and 3 were examined for size and geographic differences in capture probability. Size selectivity was tested with two Kolmogorov-Smirnov two-sample tests. The first test examined the cumulative length frequency distributions of marked Arctic grayling with those recaptured. The second test compared cumulative length frequency distributions of Arctic grayling from the first (mark event) and second (recapture event) samples. The results of these tests suggested methods to alleviate size biases (Appendix A1).

Spatial differences in capture probability were evaluated through comparisons of area specific recapture-to-catch ratios. The results of this test determined whether the abundance estimation model incorporated stratification by area. The last testable assumption was met by double marking each fish, with a tag and a fin-punch specific to the 1992 mark-recapture experiment.

Examination of the assumptions demonstrated that unlike the 1991 mark-recapture experiment, capture probabilities did not vary significantly by areas sampled, and, size selective sampling was detected, requiring the data to be stratified into size classes. To delimit the stratified size classes, an iterative series of chi-square tests was performed to find maximal differences in capture probability. The length at which the chi-square statistic was maximal demarcated the size strata.

Because the assumption of equal capture probability was upheld, the modified Petersen estimator of Bailey (1951, 1952) was selected. Use of Bailey's modification was sought because of the systematic sampling approach, and the level of mixing (localized, not complete; Seber 1982) of marked and unmarked fish over the length of the sampling area (Seber 1982). Stratified and unstratified point estimates of abundance were estimated as:

$$\hat{N} = \frac{M\,(C + 1)}{(R + 1)} \qquad (1)$$

where: M = the number of Arctic grayling marked and released during the marking event sample;

C = the number of Arctic grayling examined for marks during the recapture event;

R = the number of Arctic grayling recaptured during the second sampling event (recapture); and,

$\hat{N}$ = estimated abundance of Arctic grayling.

Variance of the abundance estimate was estimated by (Bailey 1951, 1952):

$$V[\hat{N}] = \frac{\hat{N}\,M\,(C - R)}{[(R + 1)(R + 2)]} \qquad (2)$$

Bias of this estimator was examined through comparison of the resultant point estimated abundance to the mean estimate generated using the bootstrap procedure (Efron 1982) of the mark-recapture experiment. The estimator was bootstrapped 1,000 times using the capture histories of all fish in the mark and recapture event samples, which ultimately yielded a distribution of estimates. The generalized bootstrap procedure was as follows:

1) generate a pseudorandom number (less than 1, but greater than or equal to zero) from a uniform distribution;

2) sample capture history of fish number "random number" x "total number of fish" + 1;

3) repeat 1 and 2 until a sample of "total number of fish" is taken;

4) generate abundance estimate from randomly sampled capture histories;

5) repeat 1 through 4 for 1,000 iterations; and,

6) calculate mean and variance of 1,000 iterations of abundance estimate.

Age and Size Composition

Apportionment of the estimated abundance among age or size groupings depends upon the extent of sampling biases. The outcome of tests for size selectivity and chi-square tests to detect geographic differences in capture probabilities, determined the necessary adjustments. Because size selectivity was detected, the sampled age and size compositions were adjusted by size-specific capture probabilities. The appropriate sample or samples (from the first event, second, or both events) was used to estimate the age and size compositions. To adjust age and size data, the proportion of fish at age is calculated by adjusting the number sampled at age by the ratio of capture probabilities in each size class. Capture probability was calculated as:

$$\hat{\rho_l} = \frac{RECAP_l}{MARK_l} \tag{3}$$

where: $\hat{\rho_l}$ = the capture probability of Arctic grayling in size class l, regardless of age k;

$RECAP_l$ = the number of recaptures of Arctic grayling in size class l; and,

$MARK_l$ = the number of marked Arctic grayling in size class l.

From the ratio of the largest capture probability to the capture probability in size class l, an adjustment to the number sampled at age k that is also of size class l was estimated (ignoring the hat symbols of ρ):

$$\hat{A_l} = \frac{\rho_L}{\rho_l} \tag{4}$$

where: $\hat{A_l}$ = the adjustment factor for all Arctic grayling of size class l, regardless of age class k; and,

$\rho_L = \max(\rho_l)$, $l = 1, 2, \ldots, m$ size classes.

The adjustment factor was multiplied by the number of Arctic grayling sampled at age k that are also in size class l (both samples or recapture sample alone, from inference testing):

$$\hat{x_{kl}} = \hat{A_l} \, n_{kl} \tag{5}$$

where: $\hat{x}_{k1}$ = the adjusted number of Arctic grayling of age k that are also in size class 1; and,

n_{k1} = the actual number of Arctic grayling sampled that are age k and also in size class 1.

The proportion of Arctic grayling that are age k then reevaluates to:

$$\hat{p}_k = \frac{\sum\limits_{1=1}^{m} \hat{x}_{k1}}{\sum\limits_{k=1}^{o} \sum\limits_{1=1}^{m} \hat{x}_{k1}} = \frac{\hat{x}_{k.}}{\hat{x}_{..}} \tag{6}$$

where: $k = 1, 2, \ldots, o$ age classes; and,
$1 = 1, 2, \ldots, m$ size classes.

The adjusted proportions and variances were estimated by bootstrap techniques (Efron 1982). The adjustment factors (recapture to mark ratios) were bootstrapped along with the population estimate to estimate variance of the proportions. Size composition was estimated in a similar manner, replacing age class with the Relative Stock Density (RSD) categories of Gabelhouse (1984) and incremental size categories. The RSD categories for Arctic grayling were: "stock" (150 to 269 mm FL); "quality" (270 to 339 mm FL); "preferred" (340 to 449 mm FL); "memorable" (450 to 559 mm FL); and, "trophy" (greater than 559 mm FL). Incremental size composition categories were 10 mm FL groupings with mid-points 155 to 395 mm FL.

Survival, Mortality, and Exploitation

An initial examination of survival, mortality, and exploitation was facilitated by consecutive annual stock assessments conducted in 1991 and 1992. The statewide catch and harvest estimates (Mills 1992) provided point estimates of Arctic grayling catches and harvests for the 1991 Piledriver Slough fishery.

Survival was estimated as proportion of the summed abundance from a portion of an age series at one time, that are estimated to be present at a later time (Ricker 1975). Only ages that appear to be fully recruited were used as the portion of an age series. Arctic grayling age 5 years and older were thought to be fully recruited at the time and location of the stock assessment based on abundance-at-age estimates for 1991 (Fleming 1991) and 1992. The annual rate S, was estimated as:

$$\hat{S} = \frac{\hat{N}_{t+1}}{\hat{N}_t} \tag{7}$$

where: $\hat{S}$ = the estimated proportion of Arctic grayling age 5 and up (k=5,6,7,8,9,) in year t that survive to year t+1 as age 6 and up (k = 6,7,8,9,10); and,

$\hat{N_t}$ = the summed estimated abundance of Arctic grayling age 5 years and up in year t; and,

$\hat{N_{t+1}}$ = the summed estimated abundance of Arctic grayling age 6 years and up in year t_{+1}

The variance of $\hat{S}$ was approximated with the delta method (Seber 1982; ignoring hat symbols) as:

$$V[S] \approx \left[\frac{N_{t+1}}{N_t} \right]^2 \left[\frac{V[N_{t+1}]}{[N_{t+1}]^2} + \frac{V[N_t]}{N_t^2} \right] \tag{8}$$

where the variance for N_t and N_{t+1} were each estimated as a sum of the exact variance of a product from Goodman (1960):

$$V[\hat{N_t}] = \sum_{k=5}^{9} (V[\hat{p_k}]\hat{N_{91}}^2 + V[\hat{N_{91}}]\hat{p_k}^2 - V[\hat{p_k}]V[\hat{N_{91}}]) \tag{9}$$

and;

$$V[\hat{N_{t+1}}] = \sum_{k=6}^{10} (V[\hat{p_k}]\hat{N_{92}}^2 + V[\hat{N_{92}}]\hat{p_k}^2 - V[\hat{p_k}]V[\hat{N_{92}}]) \tag{10}$$

where:

$\hat{N_{91}}$ = the abundance estimate for Arctic grayling $\geq$ 150 mm FL in 1991; the variance of N_{91} was from the bootstrapped Darroch model (reported in Fleming 1991).

$\hat{N_{92}}$ = the abundance estimate for Arctic grayling $\geq$ 150 mm FL in 1992; the variance of N_{92} was from the bootstrapped stratified Petersen model used to adjust age and size composition estimates.

$\hat{p_k}$ = the estimated adjusted fraction of the fish in age class k from 1991 and 1992 stock assessments.

The annual survival rate was converted into annual and instantaneous rates of mortality with respect to the following relationships (from Ricker 1975):

Z = the instantaneous total mortality rate;
Z = -Ln (S)
F = the instantaneous rate of fishing mortality;
M = the instantaneous rate of natural mortality;
Z = F + M;
A = the annual mortality rate;
A = 1 - e^{-z}, where e $\approx$ 2.71828;

Because statewide catch and harvest estimates have demonstrated that substantial harvest occurs on younger and smaller fish regardless of a 12 in minimum size limit (Mills 1992), exploitation and natural mortality rates were estimated for the assessed stock $\geq$ 150 mm FL. For this purpose, the survival rate estimated for fish age 5 and older was assumed to be representative and applied to the entire assessed stock. In order to apportion total instantaneous mortality (Z) among fishing (F) and natural (M) mortality components, Baranov's catch equation (Ricker 1975) was rearranged and solved for F:

$$F = \frac{Z}{A} * \frac{C}{N} \qquad (11)$$

where:

C = the 1991 estimated harvest of Arctic grayling (Mills 1992) from the Piledriver Slough fishery;

N = the 1991 abundance estimate of Arctic grayling in Piledriver Slough;

Z = the estimated total instantaneous mortality rate calculated for apparently recruited year classes (age 5 and older). Recruited year classes were age classes whose representation (proportion or abundance) <u>had</u> reached a maxima.

Before estimating natural mortality and exploitation parameters, a classification of the Arctic grayling fishery was needed to select estimator formulae. The two types proposed by Ricker (1975) are:

Type 1 = where natural mortality occurs during a time of year other than the fishing season; the population decreases during the fishing season because of catch (harvest) removals only; or,

Type 2 = where natural mortality occurs along with fishing; each occurs at a constant instantaneous rate, or the two rates vary in parallel fashion.

Based upon present insights into the basic life history for Arctic grayling, the Type 1 classification was selected. The rate of exploitation (u) estimated for a Type 1 fishery was (Ricker 1975):

$$u = 1 - e^{-F} \qquad (12)$$

The expectation of natural death was estimated (Ricker 1975):

$$v = n(1-u) \qquad (13)$$

where:
v = expectation or probability of natural death; and,
n = conditional rate of natural mortality, which is calculated as (from Ricker 1975): $n = 1-e^{-M}$

Because catch-and-release induced mortalities are likely to be latent, and not represented in reported harvests of Arctic grayling, the expectation of natural mortality is likely biased high. To offset this, a sensitivity analysis was conducted in which additions were made to the reported harvest at a level which would approximate hooking mortality. To accomplish this, the estimated catch (Mills 1992) was reduced by the estimated harvest to yield an estimate of independent catch-and-release events in 1991. The incidence of hooking mortality was set 0% and 9%, corresponding to the 95% confidence interval from a study of hooking mortality on Arctic grayling (Clark 1991). Following this adjustment to harvest, parameter estimates were re-calculated using the aforementioned formulae.

RESULTS

Field Sampling

A total of 1,799 Arctic grayling ($\geq$ 150 mm FL) were captured over a 6-day period in May. Persistent cold weather conditions delayed break-up by nearly three weeks. Water temperatures ranged between 1.8° and 5°C. The maximum daily change observed was 2.2°C, and on several occasions stream temperatures fell throughout the day. During the marking event, 1,070 fish were marked and released alive over approximately 16 km of Piledriver Slough, in the four areas. From this sample, 70 fish and 83 fish retained tags from 1990 and 1991, respectively. During the recapture event, 791 fish were captured in a single downstream pass, which included the recovery of 69 Arctic grayling tagged and released in the mark event. The tag shedding rate from the marking to the recapture event was 0%, based upon the 69 recaptures examined. This sampling event included an additional 51 fish and 59 fish captured with tags from 1990 and 1991, respectively. The annual tag shedding rate was estimated to be 2.8%, based on four tags shed among 142 Arctic grayling examined bearing tags and or finclips from the 1991 sampling. The overall acute mortality rate from the experiment was seven out of 1,799 individual Arctic grayling handled, or 0.3%. During sampling, the sex was determined for 584 Arctic grayling (178 females and 406 males) from a sample of 1,799 individuals. The smallest mature fish were 212 mm FL for females and 209 mm FL for males.

Abundance Estimation

A Kolmogorov-Smirnov comparison of cumulative distribution functions (CDF's) from the mark-recapture experiment showed that size selectivity was present in both sampling events (Figure 2A -mark vs recaptures: $D = 0.28$, $P = 6 \times 10^{-5}$; and, Figure 2B - mark vs catch: $D = 0.05$, $P = 0.20$). As a result, the abundance was estimated using a stratified approach with adjustments for size selectivity, and stock composition estimates were based upon pooled samples from both events (Case III; Appendix A1). Size strata selected for abundance estimation and corrections to stock composition estimates were: 150 to 291 mm FL, and 292 mm FL and larger, based on maximal differences of capture probability.
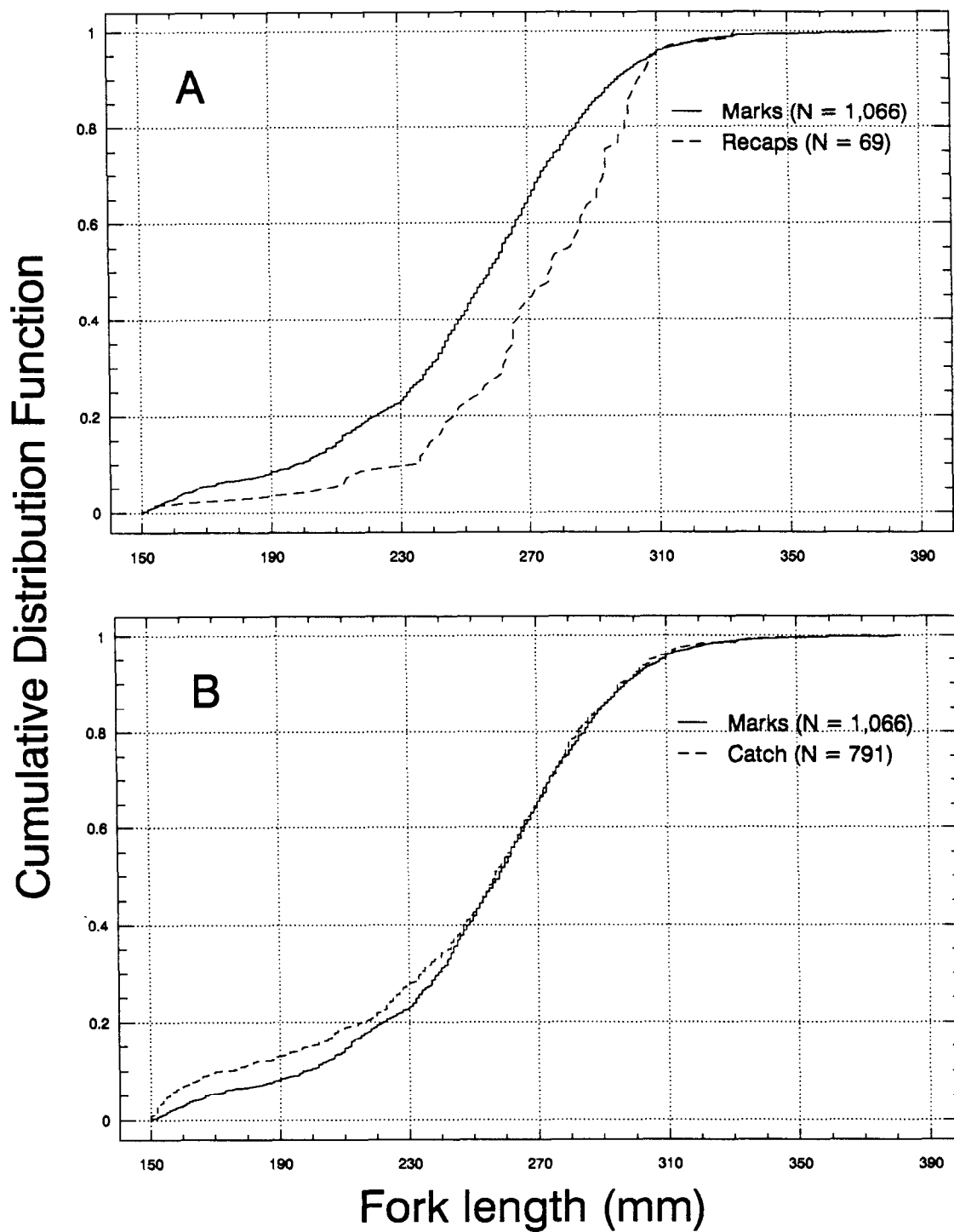
Figure 2. Cumulative distribution functions of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) in Piledriver Slough, 6 through 16 May, 1991.

Capture probabilities for the smaller stratum (Table 1) were found to be statistically similar among sampled areas when the recapture-to-catch ratios were examined by chi-square goodness of fit tests (χ^2 = 2.78, df = 3, P = 0.42). Among sampled areas in the large fish stratum (Table 2) the recapture-to-catch (R/C) ratio in the uppermost area (area 2b) was high relative to areas (3), (4a), and (4b), but it was found statistically similar when other areas were pooled (χ^2 = 3.59, df = 1, P = 0.06).

The examination of assumptions led to the use of the Bailey modification to the Petersen estimate with size stratification. The estimated abundance of small Arctic grayling, from 150 mm to 291 mm FL, was 13,330 fish (SE = 1,856, CV = 14%; Table 3). The estimate for Arctic grayling larger than 291 mm FL was 700 fish (SE = 124 , CV = 18%). The sum of stratified estimates for abundance was 14,030 Arctic grayling (SE = 1,860, CV = 13%) greater than 149 mm FL in Piledriver Slough. A bootstrapping run of the Bailey estimator, with 1,000 iterations resulted in abundance estimates of 13,373 small fish (SE = 1,423 fish, CV = 11%) and 725 larger fish (SE = 52 fish, CV = 7%) with a sum of stratified estimate that was 14,098 fish (SE = 1,424 fish, CV= 10%). The closeness of the point estimate and the bootstrapped mean estimate indicated very little if any statistical bias existed within the mark-recapture experiment.

Age and Size Composition

Ages observed for Arctic grayling in Piledriver Slough ranged from 2 to 9 years, with 5 years as the median age. The predominant age class present in Piledriver Slough was age 5 (32% of the stock; Table 4) followed by age 4 (25% of the stock). Stock-sized fish comprised 71% of the assessed stock, while 28% were of quality-size (Table 5). Incremental size compositions and abundances for 1991 and 1992 (Figure 3) indicate similarity of the size structure but a slight decline in abundance of legal-sized Arctic grayling ($\geq$ 260 mm FL) available to anglers in 1992.

Survival, Mortality, and Exploitation

Survival was estimated for the fully recruited portion of the population, which for the Piledriver Slough stock included Arctic grayling age 5-years and older. In 1991, there were an estimated 10,309 fish age 5 years and up (Table 6). Following the 1991 fishery, and overwintering to 1992, it was estimated that 3,671 fish age 6 years and older, or 36% (SE = 4%), had survived. The 95% confidence range of the survival rates fell between 27 to 44%. The total instantaneous rate of mortality, Z, was estimated to be 1.03. These rates were then applied to all fish within the assessed population.

Following the 1991 fishing season, Mills (1992) estimated that 30,012 captures of Arctic grayling in Piledriver Slough resulted in a harvest of 3,987 fish. In 1991 it was estimated that 17,323 Arctic grayling inhabited the slough during May, on or about the start of the fishery. By subtracting the harvest from the total captures, the number of independent catch-and-release events was estimated (26,025). The introduction of hooking mortality as a variable,

Table 1. Numbers of marked and recaptured small (150 to 291 mm FL) Arctic grayling and tabulation of catches and recaptures by area in Piledriver Slough, 13 through 18 May 1992.

| Marking event | | Area recaptured[a] | | | | Recovered | |
Number marked	Area	2b	3	4a	4b	Yes	No
146	2b	7	2	0	0	9	137
166	3	1	18	5	0	24	142
373	4a	0	2	6	0	8	365
235	4b	0	0	2	3	5	230

Total 920

	2b	3	4a	4b			
Recaptured (R)	8	22	13	3	$\sum$ = 46	874	
Unmarked (U)	99	243	257	35	$\sum$ = 634		
Catch (C)	107	265	270	38	$\sum$ = 680		
R/C Ratio[b]	0.07		0.05				
		0.08		0.08			

[a] Areas for the mark-recapture experiment were delineated from existing landmarks (see Figure 1) and or access points to more remote sections.

[b] Capture probabilities were tested for statistical similarity using chi-square tests on numbers of recaptured (R) and examined (C) Arctic grayling. Failure to reject the null hypothesis of similarity between adjacent areas (χ^2 = 2.78, 3 df, P = 0.42) suggests that no area-specific differences in capture probability existed within the size stratum.
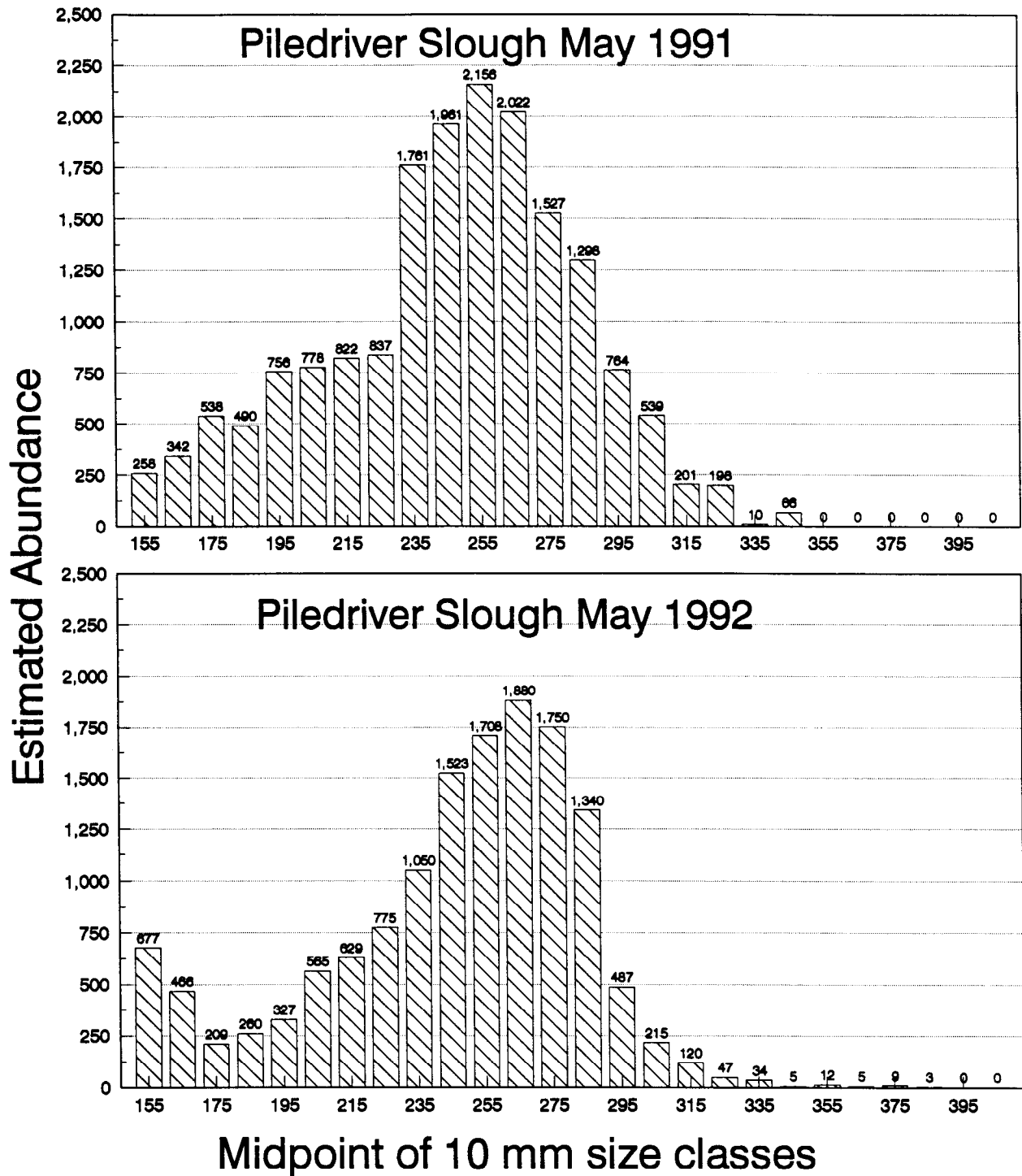
Figure 3. Apportionment of estimated abundance across 10 mm FL incremental size categories for Arctic grayling (≥ 150 mm FL) present in Piledriver Slough during May 1991 and 1992.

Table 2. Numbers of marked and recaptured large (≥ 292 mm FL) Arctic grayling and tabulation of catches and recaptures by area in Piledriver Slough, 13 through 18 May 1992.

	Marking event		Area recaptured[a]				Recovered	
	Number marked	Area	2b	3	4a	4b	Yes	No
	33	2b	4	0	1	0	5	28
	40	3	0	18	0	0	10	30
	53	4a	1	0	5	0	6	47
	24	4b	0	0	1	1	2	22
Total	150	Recaptured (R)	5	10	7	1	$\sum$ = 23	127
		Unmarked (U)	7	43	35	3	$\sum$ = 88	
		Catch (C)	12	53	42	4	$\sum$ = 111	
		R/C Ratio[b]	0.42	0.17				
			0.19		0.25			

[a] Areas for the mark-recapture experiment were delineated from existing landmarks (see Figure 1) and or access points to more remote sections.

[b] Capture probabilities were tested for statistical similarity using chi-square tests on numbers of recaptured (R) and examined (C) grayling. The failure to reject the null hypothesis of similarity between adjacent areas (3), (4a), and (4b) allowed their grouping (χ^2 = 0.19, 2 df, P = 0.91). Subsequent comparison of area (2b) to area (3-4a-4b) led to a failure to reject the null hypothesis of similarity (χ^2 = 3.59, 1 df, 0.05 P = 0.06), indicating that no significant differences in capture probability existed within the size stratum.

Table 3. Size-stratified abundance estimates of Arctic grayling ($\geq$ 150 mm FL) in Piledriver Slough.

Length category	Mark M	Catch C	Recap R	ρ[a]	SE[ρ][b]	N[c]	SE[N][d]
150 to 291 mm	920	680	46	0.05	<0.01	13,330	1,856
$\geq$ 292 mm	150	111	23	0.15	0.02	700	124
Total	1,070	791	69	---	---	14,030	1,860
Unstratified	1,070	791	69	---	---	12,106	1,371

[a] ρ is the point estimated probability of capture.
[b] SE[ρ] is the standard error of ρ determined from bootstrap methods.
[c] N is the point estimated abundance in a stratified length category or unstratified population.
[d] SE[N] is the standard error of N.

Table 4.   Estimates of the sampled and adjusted contributions by each age class for Arctic grayling (≥ 150 mm FL) captured in Piledriver Slough, 13 through 16 May 1992.

Age	Sampled						Adjusted[a]		
	n[b]	p[c]	SE[d]	FL[e]	SD[f]	n[g]	N[h]	p[i]	SE[j]
1	0	0.00	- - -			0	0	0.00	- - -
2	59	0.06	0.01	164	13	59	961	0.07	0.01
3	82	0.09	0.01	204	22	82	1,345	0.10	0.01
4	215	0.23	0.01	235	21	215	3,513	0.25	0.02
5	293	0.31	0.01	262	20	293	4,540	0.32	0.02
6	212	0.22	0.01	280	21	212	2,866	0.20	0.02
7	56	0.06	0.01	292	25	56	633	0.05	0.01
8	17	0.02	<0.01	308	23	17	127	0.01	<0.01
9	5	<0.01	<0.01	314	40	5	45	<0.01	<0.01
	939	1.00					14,030	1.00	

[a] Age composition was adjusted only for size selectivity using bootstrapping procedures.

[b] n = sample size.

[c] p = proportion of sampled Arctic grayling from marking event.

[d] SE = standard error of the sampled proportion.

[e] FL = mean fork length-at-age based upon 939 age:length combinations from the mark event, 13 through 16 May 1992.

[f] SD = sample standard deviation.

[g] n = sample size for mean fork length at age.

[h] N = estimated abundance by age classes at the time of recapture event.

[i] p = adjusted proportion of Arctic grayling (≥ 150 mm) in stock.

[j] SE = standard error of the adjusted proportion, as calculated using the bootstrapped variance and the delta method (Seber 1982).

Table 5. Summary of Relative Stock Density (RSD) indices for Arctic grayling ($\geq$ 150 mm FL) captured at Piledriver Slough in 1990, 1991, and 1992.

| | RSD Category[a] | | | | |
	Stock	Quality	Preferred	Memorable	Trophy
1990[b]					
Number sampled	1,217	150	1	0	0
Adjusted RSD[c]	0.85	0.14	<0.01	---	---
Standard Error	0.03	0.03	<0.01	---	---
CV(%)	4	23	66	---	---
Abundance[d]	13,969	2,347	15	---	---
1991					
Number sampled	882	320	4	0	0
Adjusted RSD[e]	0.73	0.26	<0.01	---	---
Standard Error	0.01	0.01	<0.01	---	---
CV (%)	2	6	50	---	---
Abundance	12,645	4,504	52	---	---
1992					
Number sampled	683	375	8	0	0
Adjusted RSD[f]	0.71	0.28	<0.01	---	---
Standard Error	0.01	0.01	<0.01	---	---
CV (%)	2	4	45	---	---
Abundance	10,017	3,970	28	---	---

[a] Minimum lengths for RSD categories are (Gabelhouse 1984):
  Stock   - 150 mm FL;
  Quality   - 270 mm FL;
  Preferred - 340 mm FL;
  Memorable - 450 mm FL; and,
  Trophy   - 560 mm FL.

[b] Arctic grayling were sampled from several sites in Piledriver Slough in a 1990 mark-recapture study (Timmons and Clark 1991) between 25 April and 5 October 1990. In 1991, a mark-recapture study was conducted in the same area but over a shorter duration, from 6 through 16 May.

[c] The adjustments made in the 1990 analysis were to correct for size selectivity and a differential capture probability by area.

[d] Apportioned abundances from the 1990 (Timmons and Clark 1991), 1991 (Fleming 1991), and 1992 (this report) stock assessments.

[e] The required adjustment made in the 1991 analysis involved a differential capture probability by area, but no changes were made to the RSD sample proportion by size specific capture probabilities.

[f] Adjustments for size selectivity were used in the 1992 assessment.

Table 6. Estimates of age-specific abundances and standard errors for Arctic grayling ($\geq$ 150 mm FL) resident to Piledriver Slough during May 1991, and 1992.

| Age Class | May 1991 estimate[a]: | | | | May 1992 estimate[b]: | | | |
	p[c]	n[d]	SE[e]	CV[f]	p[g]	n	SE[h]	CV
1	0.00	0	---	--	0.00	0	---	--
2	0.02	274	77	28	0.07	961	219	23
3	0.14	2,373	247	10	0.10	1,345	186	14
4	0.25	4,367	352	8	0.25	3,513	428	12
5	0.34	5,919	422	7	0.32	4,540	513	11
6	0.16	2,832	276	10	0.20	2,866	367	13
7	0.07	1,187	171	14	0.05	633	167	26
8	0.02	371	92	25	0.01	127	44	35
9	0.0	0	--	--	<0.01	45	15	36
10	0.0	0	--	--	0.0	0	--	--
Totals	1.0	17,323	---	--	1.0	14,030	---	--

[a] Stock assessment in 1991 occurred between 6 and 16 May. A bootstrapped Darroch estimator was used because of variation in capture probability and incomplete mixing.

[b] Stock assessment was conducted between 13 and 18 May. Bailey's modification to the Petersen estimator was used.

[c] p = adjusted proportion of Arctic grayling in the population at the time of the second sampling event, 13 to 16 May, 1991. The sample composition was adjusted only by the apportionment of the estimated abundance among the areas sampled using the delta method (Seber 1982).

[d] n = estimated abundance apportioned for each age.

[e] SE = standard error of the age-apportioned abundances (n) calculated from the variance of a product (Goodman 1960).

[f] CV = coefficient of variation of n expressed as a percentage.

[g] p = the adjusted proportion at age at the time of the first (marking) event, 13 to 16 May, 1992. Adjustments were made to composition estimates to compensate for differential capture probability by size.

[h] SE = standard error of the age-apportioned abundances (n) calculated from the variance of a product (Goodman 1960).

using 0% (Mills 1991 harvest) and 9% hooking mortality, increased the reported harvest figures by 2,343 fish to 6,330 fish, which was a relative increase of 59%. The instantaneous rate of fishing mortality, F, was calculated by Baranov's catch equation using each harvest scenario. Instantaneous fishing mortality (F) was estimated at 0.37 for the reported harvest, and when adjusted for hooking mortality it was 0.58. Exploitation rates, or expectation of death attributable to the fishery (u), and the expectations of natural death (v) were estimated under both harvest scenarios. The rates were as follows:

Source of Mortality:	Mills 1992 Harvest	Mills 1991 Harvest *with* Hooking Mortality
Fishery:	$u = 0.31$	$u = 0.44$
Natural:	$v = 0.33$	$v = 0.20$
Total:	$A = 0.64$	$A = 0.64$

DISCUSSION

The annual stock assessment of Arctic grayling in Piledriver Slough was delayed by a late spring break-up until mid-May, and included a smaller portion of the entire slough than past assessments. Heavy accumulations of aufeis and several beaver dams blocked spring migrations of Arctic grayling to headwater areas of Piledriver Slough and 23 Mile Slough. Thick ice accumulations and evidence of winter-killed fish were found in upper areas where in 1990 spawning concentrations were observed. Likewise, within 23 Mile Slough, warmer stream temperatures and concentrations of spawning Arctic grayling were observed in 1991. These observations attest to the large year-to-year variation in habitat availability and physical conditions observed in three years of spring assessments at Piledriver Slough. Information gathered in 1991 suggested a more cost-effective approach to stock assessment by removing sampling areas below the Eielson Farm Road, including the lowest reach of Piledriver Slough and adjoining Moose Creek.

The unexpected loss of headwater sampling areas, and the planned reductions to sampling in lower Piledriver Slough resulted in a 16 km sampling area, roughly half the 1991 sampling area. In 1990 and 1991, investigations found capture probabilities in the small headwater areas to be significantly higher than the middle and lower areas of the slough which led to complications in abundance estimation. In past investigations at Piledriver Slough, the methods of Darroch (1960) were used to correct for incomplete mixing and geographic differences in capture probability. Unlike 1992, no adjustments for data collected in 1990 and 1991 were necessary to correct for size-selective sampling of fish larger than 149 mm FL. Bailey's modification to the Petersen

estimator with size stratification was used in 1992 because of findings of similar capture probability by area, but not by size.

Approximately 14,030 fish greater than 149 mm FL were estimated to be in Piledriver Slough, in densities of approximately 875 per km. It is likely that this density may be biased high due to the lack of available habitat in May 1992. The age and size compositions of Arctic grayling appeared to have been very similar to May 1991 estimates. Full recruitment was estimated as the age at which maximal abundance-at-age repeatedly occurs in the assessment; in Piledriver Slough this occurred at age 5 in 1991 and 1992, which corresponds to a mean fork length of 262 mm, which is approximately the legal size limit. Age of full recruitment has been found to occur at age 3 for Arctic grayling in other Tanana drainage assessed stocks. It is likely that pre-recruit abundance may be under-represented in our estimates, and that the balance of younger Arctic grayling were outside the study area. Very few preferred size and larger Arctic grayling (>339 mm FL) were sampled and the estimated numbers for these larger fish remain low relative to other assessed stocks. Combinations of the characteristically slow growth (Fleming 1991), natural mortality, and angler harvest may act together and result in this finding.

It is likely that the timing of seasonal immigration, or a tendency to reside in streams other than Piledriver Slough as juveniles and sub-adults may influence patterns of Arctic grayling recruitment observed in 1991 and 1992. Delayed timing of immigration by immature individuals into spawning areas has been observed in several studies where Arctic grayling were trapped during spring migrations to spawning areas (Ridder 1983, Fleming 1989). Tagging information has documented the emigration of fish tagged in Piledriver Slough to the adjacent Moose and French creeks, and several recoveries have been made in the Salcha and Chena rivers. Limited immigration from the Salcha and Chena rivers has also been detected through tag recoveries. Evidence contradictory to these hypotheses of immigration or emigration was found in August 1991 when no apparent changes were found in size composition from May 1991 samples, and from mixing rates it was estimated that nearly all (~ 97%) tagged fish present in August were present earlier in May (Fleming 1991).

Although our understandings of the recruitment process is not complete, initial estimates of survival, mortality, and exploitation were generated from information gathered from the fully recruited portion of the population. Overall survival was estimated to be 36% for fish 5 years and older in May 1991, that survive fishery and natural mortalities, to May 1992. When survival is estimated to be this low and seemingly unsustainable, other phenomena such as emigration (permanent or temporary), as mentioned earlier, may mask the "true" (life or death) survival rates. Thus survival (and mortality) estimates may be biased if the assumption of fidelity to PDS for spawning and summer rearing is untrue. Because some movement of Arctic grayling from PDS into other streams has been detected, it is likely that PDS is not a completely closed system relative to Arctic grayling. What needs to be yet determined is the extent of movement and what percentage of movement at a given time of year is deemed meaningful for management purposes. For example, a 3% straying of the Arctic grayling population to streams other than

PDS during spawning may result in a very small bias in survival and mortality estimates.

Although net ageing bias for Arctic grayling has been examined and found to be negligible using mark-recapture age data (Merritt and Fleming 1991), the slow growth of fish in Piledriver Slough may affect our abilities to detect the accumulation of annuli and assign accurate ages. Given the present constraints of only two similarly designed field investigations in consecutive years, the survival estimator used is likely to offer the most robust approach when ageing error may exist.

The partitioning of mortality among fishery and natural forms requires insight into the timing of annual mortalities with respect to timing of the fishery, and accuracy of additional input variables, such as harvest. Given present and past findings of low rates of survival and growth potential, the relatively short duration (4-5 months) of the fishery, and a generally accepted life history pattern of spawning and feeding heavily during the short summer, the majority of natural mortality likely occurs during winter. The Type 1 fishery classification of Ricker (1975) was better suited to the Piledriver Slough Arctic grayling fishery than the Type 2 classification, in which natural mortality occurs at a constant rate.

Statewide catch and harvest surveys for 1991 indicated that the catches of Arctic grayling were far in excess of the estimated abundance in Piledriver Slough. When a significant portion of the reported catch is released, in this case 26,025 of 30,012 captures, it is likely that some released fish die of capture related injuries. Creel surveys at Piledriver Slough (Hallberg and Bingham 1991) reported that approximately 85% of catches and 94% of harvests occurred during the first half of the season (May-June), which corresponds to angling pressure on Arctic grayling in prespawning, spawning, and post-spawning condition. Studies on hooking mortality have suggested effects of hooking stresses may likely fluctuate with increases to, or decreases to overall condition (Marnell and Hunsaker 1970, Wydoski 1977, and Titus and Vanicek 1988). Catch and release of fish which have recently recovered from overwintering, migration, and spawning is likely to adversely affect the overall condition of Arctic grayling and increase their susceptibility to latent hooking mortality. A sensitivity analysis using a "best" and "worse" case situation of latent hooking mortalities used estimates of 0% and 9%, from Clark (1991). Harvest estimates for 1991 (Mills 1992) increased relatively by 0% and 59%, respectively. Both harvest scenarios resulted in exploitation rates that exceeded the present management cap (20%). The 13% increase in exploitation from 31% to 44% represented a relative change or shift of up to 41% of annual mortality from natural to fishery causes. Overall, this sensitivity analysis indicates how sensitive management criteria can be to effects of hooking mortality in this high-use Arctic grayling fishery.

The Arctic grayling population that was in Piledriver Slough at the time of assessment appears to be of similar abundance and composition as seen in 1991. The delaying of full recruitment until age 5 may indicate that younger fish may not be fully represented in these assessments, and accounts for the appearance of a slight decrease in population abundance. At this time, estimates of survival, and mortality, and exploitation indicate fishing

pressures on the assessed portion of the population are high relative to management goals. It is likely that true annual rates for natural and fishery induced mortalities are between results estimated by this investigation. Because hooking injury and latent mortalities are generally unquantified with regards to harvest estimates, these mortalities by default are incorrectly "lumped" with natural mortality, which can lead to underestimation of exploitation rates and increased management risks. Future stock assessment investigations should continue to occur during May, track abundances at age and recruitment patterns, and carefully monitor survival and exploitation.

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APPENDIX A

Appendix A1. Methodologies for alleviating bias due to gear selectivity by means of statistical inference.

Result of first K-S test[a]	Result of second K-S test[b]

<u>Case I[c]</u>

    Fail to reject H_0 Fail to reject H_0

    Inferred cause: There is no size-selectivity during either sampling event.

<u>Case II[d]</u>

    Fail to reject H_0 Reject H_0

    Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event

<u>Case III[e]</u>

    Reject H_0 Fail to reject H_0

    Inferred cause: There is size-selectivity during both sampling events.

<u>Case IV[f]</u>

    Reject H_0 Reject H_0

    Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.

---

[a] The first K-S (Kolmogorov-Smirnov) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification.
If stratified and unstratified estimates are dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities.
If stratified and unstratified estimates are similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.

APPENDIX B

Evaluation of stocked rainbow trout survival rates in Piledriver Slough, 1991 to 1992.

INTRODUCTION

In response to increased sport fishing pressure in the Interior and overfishing of some indigenous stocks, annual stockings of rainbow trout into Piledriver Slough was begun in 1987 and is planned to continue through at least 1995 (Piledriver Slough Fisheries Management Plan 1992). Stocking of the slough has created a very popular sport fishery; angler-days reached a high of 27,705 in 1990, and rainbow trout harvest in Piledriver Slough was 15.7% of the total rainbow trout harvest in the Tanana drainage in 1988 (Appendix B1).

The objective of this study was to determine the over-winter survival rate of rainbow trout stocked in 1991. Additionally, survival of the remaining 1990 stocking cohort of rainbow trout was estimated.

METHODS

Field Sampling

A mark-recapture experiment to estimate the post-winter abundance of rainbow trout was conducted in conjunction with the annual stock assessment of Arctic grayling. Field sampling was the same as that reported for Arctic grayling. During the marking event, rainbow trout were measured, tagged with individually numbered Floy FD-67 tags, and given an upper caudal fin punch as a secondary mark to detect tag loss, if it occurred, between events. Fish stocked in 1990 all had adipose fin clips, which were recorded along with old fin clips and tag numbers from fish captured that were sampled in 1990 and 1991. All information was recorded directly onto Tagging-Length mark-sense forms (Version 1.0).

During the recapture event, tag numbers of fish recaptured from the marking event were recorded, and newly captured fish were not given fin clips or tags.

Estimation of Abundance and Survival

The Bailey modification of the Petersen mark-recapture method (Bailey 1951, 1952, Seber 1982) was used to estimate the number of rainbow trout remaining in Piledriver Slough prior to stocking in 1992. The use of a closed model abundance estimator assumes the following (Seber 1982):

1) there is no change in population size between events (i.e. the population is closed to recruitment and mortality);

2) marking of rainbow trout does not affect their probability of capture in the second sample;

3) rainbow trout do not lose their mark between sampling events, and;

4) all rainbow trout have the same probability of capture during the first sample or in the second sample or marked and unmarked rainbow trout mix randomly between the first and second samples.

Appendix B1. Effort and harvest of rainbow trout at Piledriver Slough and in the Tanana River drainage, 1983-1991.

	Piledriver Slough					Tanana River Drainage		% of Tanana River Drainage[h]	
Year	Number of Anglers	Number of Trips	Days Fished	Catchable Size Trout Stocked	Harvest of Rainbow Trout	Days Fished	Rainbow Trout Harvest	Days Fished	Rainbow Trout Harvest
1983[a]			4,148	0	0	146,386	20,664	2.8	0
1984[b]	470	2,334	4,651	0	0	145,752	34,022	3.2	0
1985[b]	648	3,019	2,133	0	0	136,422	33,432	1.6	0
1986[b]	342	1,870	2,079	0	0	144,937	31,270	1.4	0
1987[c]	4,686	15,236	13,247	12,495	4,346	156,061	31,824	8.5	13.7
1988[d]	4,981	21,936	24,375	26,544	12,296	174,554	78,345	14.0	15.7
1989[e]	5,268	19,512	22,746	25,655	7,689	186,418	74,675	12.2	10.3
1990[f]	6,313	23,024	27,705	20,000	8,052	184,887	64,143	15.0	12.5
1991[g]	5,308	15,365	17,703	25,143	6,414	155,663	72,024	11.4	8.8

[a] Mills 1984
[b] Mills, unpublished data.
[c] Mills 1988.
[d] Mills 1989.
[e] Mills 1990.
[f] Mills 1991.
[g] Mills 1992.
[h] Percent of Tanana River drainage fishery represented by Piledriver Slough.

The first assumption was met by the short hiatus between sampling events. The second assumption was examined using a chi-square test for similar capture probability in areas where recaptures occurred. The third assumption was met by double marking each rainbow trout with a fin punch as well as a tag. The last assumption was met following the use of Kolmogorov-Smirnov two sample tests which examined differences in capture probabilities by size of fish, and change in size composition between sampling events. Mixing could not be evaluated because of small sample sizes, but local mixing was assumed to have occurred between events.

The point estimate of abundance was calculated with the Petersen estimator of Bailey (Bailey 1951, 1952; see equations 1 and 2 in main body of this report).

Proportions of fish with adipose clips were compared using a chi-square test in order to determine if those rainbow trout stocked in 1990 had equal probability of being captured in both events in 1992. If proportions were similar, the proportion of adipose clips in the sample was used to estimate the number of fish stocked in 1990 present in the population:

$$\hat{N_t} = \hat{N} \times \hat{P_t} \tag{B.1}$$

where:

$\hat{N_t}$ = estimated abundance of 1990 or 1991 stocking cohorts, stocking cohorts are hereafter referenced as (90) or (91);

$\hat{P_t}$ = proportion with stocking cohort mark (adipose clip = 1990, no clip = 1991)

The variance for each cohort abundance was estimated as a sum of the exact variance of a product from Goodman (1960):

$$V[\hat{N_t}] = (V[\hat{P_t}]\hat{N}^2 + V[\hat{N}]\hat{P_t}^2 - V[\hat{P_t}]V[\hat{N}]) \tag{B.2}$$

Survival rate for fish stocked in the 1991 that survived from 1991 to 1992 was estimated as a ratio of an estimated abundance to a known abundance:

$$\hat{S}(91) = \frac{\hat{N}(91)}{\text{number stocked in 1991}} \tag{B.3}$$

The variance for the estimated survival was then calculated as:

$$V[\hat{S}(91)] \approx \left[\frac{V[\hat{N}]}{\text{number stocked 1991}^2} \right] \tag{B.4}$$

Survival rate from 1991 to 1992 was estimated for the 1990 stocking cohort. This was estimated from a 1991 abundance estimate of the 1990 stocking cohort (Timmons 1992), which then survived to 1992:

$$\hat{S}(90) \approx \left[\frac{\hat{N}(90),92}{\hat{N}(90),91} \right] \qquad (B.5)$$

where:

$\hat{N}(90),92$ = abundance of the 1990 stocking cohort in 1992;

$\hat{N}(90),91$ = abundance of 1990 stocking cohort in 1991 (Timmons 1992).

The variance of survival for the 1990 stocking cohort was then estimated by (Seber 1982; ignoring hat symbols):

$$V[S(90)] \approx \left[S(90) \right]^2 \left[\frac{V[N(90),92]}{[N(90),92]^2} + \frac{V[N(90),91]}{[N(90),91]^2} \right] \qquad (B.6)$$

RESULTS

A total of 21 rainbow trout were marked and released in the first event. In the second event, 23 rainbow trout were captured, six of which were recaptures from the first event. In areas with recaptured fish (areas 2 and 4), there were no significant differences in capture probability based on the chi-square test (χ^2=0.24 , df=1, P = 0.62). This satisfied the assumption that marking in the first event did not affect the probability of capture in the second event.

Kolmogorov-Smirnov tests showed no significant difference in capture probabilities by size of fish (D=0.23, P=0.95; Appendix B2); and no significant change in size composition between events (D=0.27, P=0.41; Appendix B3). This allowed calculation of abundance without adjustments for size selectivity, and satisfied the assumption that all trout had an equal probability of being captured in the first or second sampling events.

Estimated abundance of rainbow trout was 72 fish (SE=21). A chi-square test comparing proportions of fish with adipose clips in the two sampling events resulted in no significant differences (χ^2 = 0.0, df=1, P = 1). Since the proportion of adipose clips was similar between events, the estimated number of fish surviving from the 1990 and 1991 stockings were apportioned from the overall abundance estimate. The estimated abundances were nine rainbow trout (SE=4) from the 1990 stocking, and 63 rainbow trout (SE=19) from the 1991 stocking, based on a sample with 12.8% adipose clips.
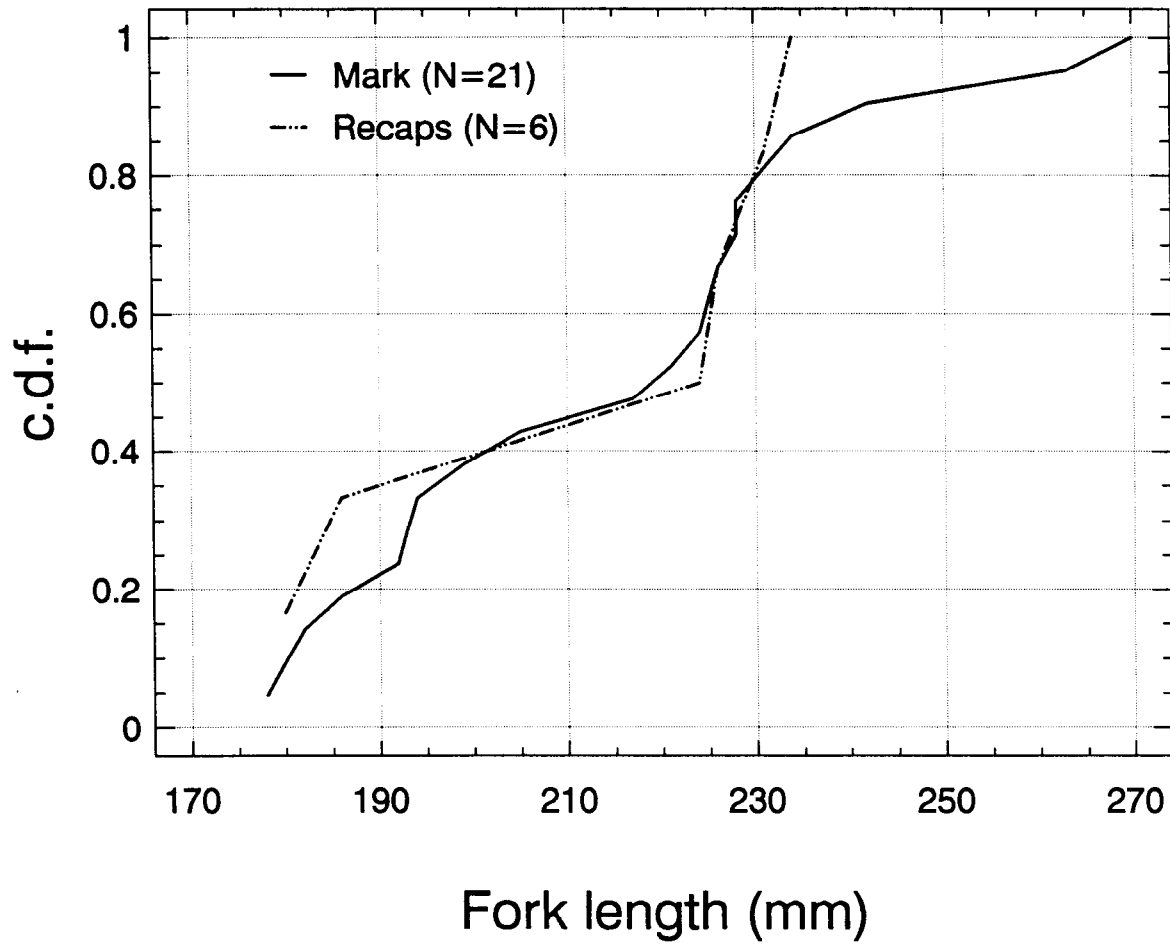
Appendix B2. Cumulative distribution function of lengths of rainbow trout marked versus lengths of rainbow trout captured in Piledriver Slough, 13 through 18 May, 1992.
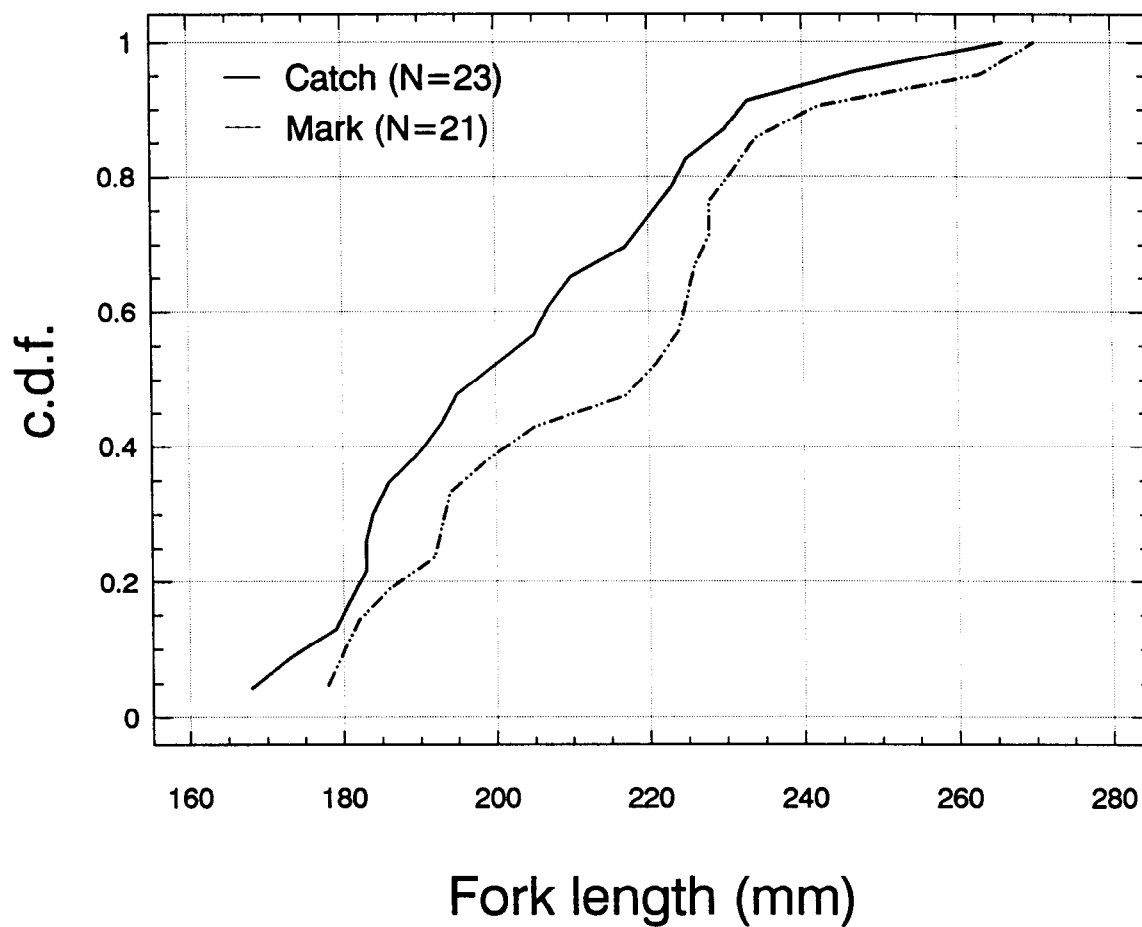
Appendix B3. Cumulative distribution function of lengths of rainbow trout marked versus lengths of rainbow trout examined for marks in Piledriver Slough, 13 through 18 May, 1992.

Survival rate of 25,100 fish stocked in 1991 was 0.25% (SE=0.076% ; CV= 30%).
Survival rate for the 1990 stocking cohort, during 1991 to 1992 was 1.67%;
(SE=0.84; CV=50%).

DISCUSSION

It is clear from the results of the abundance estimates and survival rates
that stocked rainbow trout have very low survival rates in Piledriver Slough.
Survival rate of the 1991 stocking appeared lower than the 2% rate estimated
for fish stocked in 1990 that survived to 1991 (Timmons 1992). Fish stocked
in 1990 tended to have a higher 1991-1992 survival rate (1.67%) than those
stocked in the summer of 1991 (0.25%), although they were not significantly
different. One explanation for the higher observed survival rates of the
residual 1990 cohort could be that the fish had some level of fidelity to
previously successful overwintering areas, while the 1991 cohort did not. A
number of unidentified decomposed fish carcasses were observed in areas with
heavy ice accumulation and delayed melting, specifically in area 1. In these
areas, complete freeze-up and dewatering, anaerobic conditions, or starvation
could have occurred during the winter of 1991-1992. Low rates of survival for
rainbow trout may indicate lower tolerances than indigenous species, such as
Arctic grayling, to lower levels of dissolved oxygen. In a limnological
investigation reported by Rahel (1990), rainbow trout failed to survive in
Gelatt Lake, Wyoming during the 1987-88 winter. Interestingly, the other five
species in the lake survived, including Arctic grayling. Other mechanisms
that could decrease survival rate might include emigration from Piledriver
Slough, or predation by indigenous species such as northern pike *Esox lucius*
and burbot *Lota lota*, in the lower portions of Piledriver Slough, Moose Creek
and the confluence with the Tanana River. At the present time no evidence has
been found documenting emigration of stocked rainbow trout to other areas, or
linking predation to the observed survival.

With a put-and-take fishery where annual survival is low, a high number or
proportion of stocked fish must be harvested by anglers to derive maximal
benefits from the stocking. Based on past stocking levels and reported
harvests, the percentage of rainbow trout harvested each season has ranged
from a low of 25% in 1991 to a high of 46% in 1988. With such harvested
fractions, natural mortality may account for between 54 and 74% of the total
mortality.